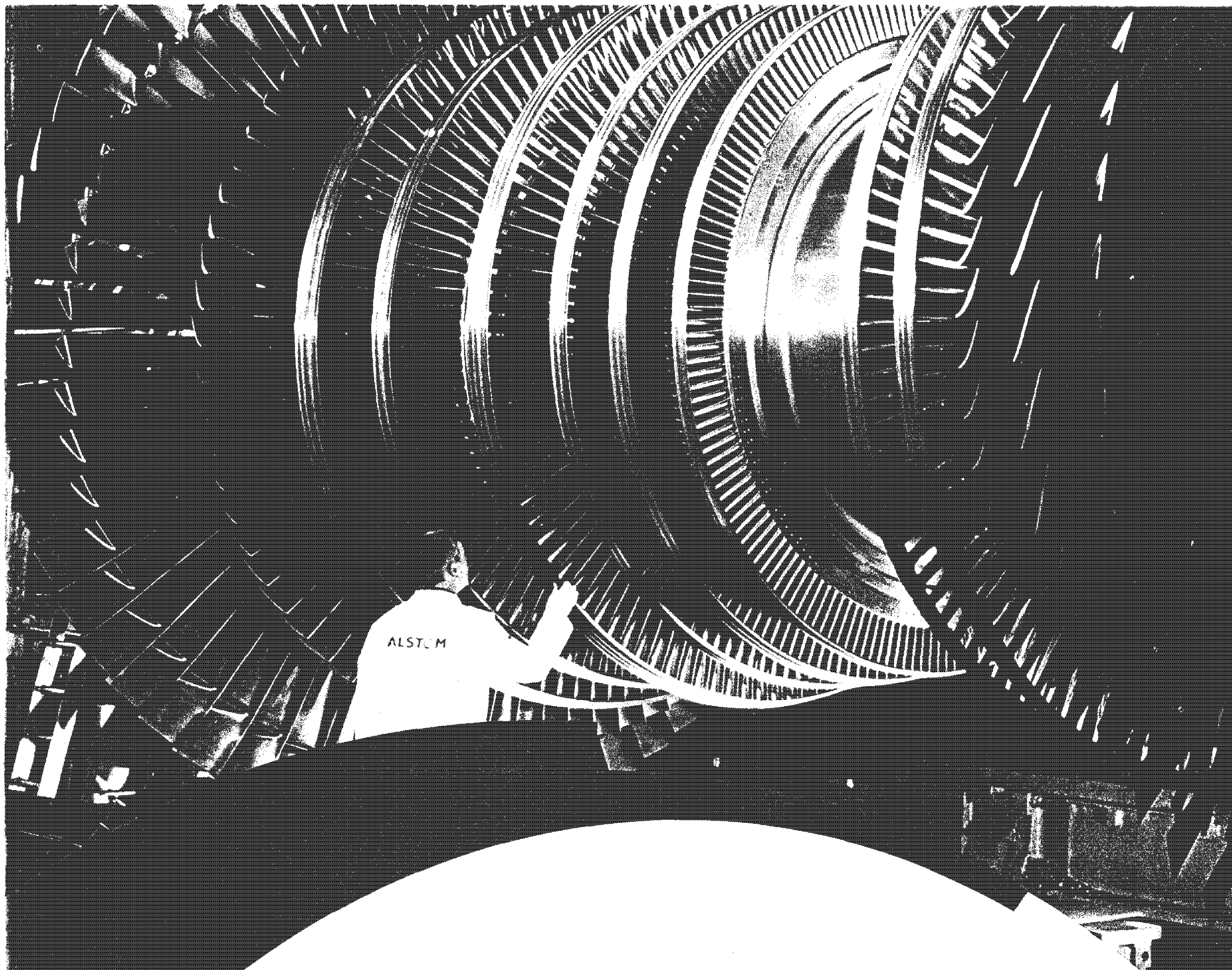

Efficiency Improvement Features of Recent ALSTOM Power HP/LP Turbine Retrofit at Southern California Edison's San Onofre Nuclear Generating Station

ALSTOM

Power
Steam Turbines

IP7011274

Efficiency Improvement Features of Recent ALSTOM Power HP/LP Turbine Retrofit at Southern California Edison's San Onofre Nuclear Generating Station

Robert D. Brown, ALSTOM Power, Rugby, England. Tel. +44 (0) 1788 531924
robert.brown@power.alstom.com
Fred Y. Simma, Southern California Edison, San Clemente, California, USA. Tel. 949 368 2306
simmaf@songs.sce.com
Russell J. Chetwynd, Southern California Edison, San Clemente, California, USA. Tel. 949 368 2306
chetwyndr@songs.sce.com

Abstract

A large US nuclear utility was faced with a necessity to perform numerous plant physical and operational modifications during the 1999 refuelling outages. In particular, it replaced low pressure (LP) turbines, high pressure (HP) turbine diaphragms, reduced steam generator operating temperature and pressure and made modifications to the main condenser. The significant performance improvements obtained from the LP turbine retrofit have offset the performance loss necessary to preserve steam generator life. The LP turbines have been retrofitted to address reliability problems associated with stress corrosion cracking (SCC). This opportunity was used to boost their performance with innovative ALSTOM Power design features. These included the unique "optiflow" steam flow arrangement six stages of integrally shrouded blades, a new 47" last stage blade, and generously sized aerodynamically efficient hoods with customized diffusers.

The HP turbines have been rematched, with only 3 stages of diaphragm replacement, to permit operation at full reactor thermal power with increased volumetric steam flow due to reduced steam generator temperature and pressure.

In order to quantify the LP turbine efficiency improvement, the performance impact of the multiple modifications was separated. Back-to-back performance tests were performed before and after each outage. The challenge was to obtain reliable results without incurring the considerable expense of performing a full performance test per ASME code PTC 6. An acceptably low uncertainty level was achieved using multiple station instrumentation and a few additional test quality instruments.

The utility and OEM approaches and finding that related to the overwhelming success of the project is discussed as well as a summary of the work performed. This paper will be of interest to utilities with a need to resolve turbine reliability issues, perform a power upgrade and also maximize & quantify performance improvement.

Nomenclature

SCC	Stress Corrosion Cracking
LP	Low Pressure Turbine
HP	High Pressure Turbine
SONGS	San Onofre Nuclear Generating Station
SCE	Southern California Edison
OEM	Original Equipment Manufacturer
PWR	Pressurized Water Reactor
MSR	Moisture Separator Reheater
SG	Steam Generator
NDE	Non Destructive Examination
RCS	Reactor Cooling System

Introduction

SONGS has two almost identical Nuclear Units. Each Unit consists of a 3410 MWth, pressurized water, Nuclear Steam Supply System. The steam generators were designed to deliver 855 psia saturated steam to the turbine inlet at 100% rated power.

The original 1800 rpm, 1127 MWe rated steam turbines entered service in 1983 and 1984 respectively. Both units had accumulated in excess of 100,000 operating hours before the installation of the turbine retrofits. Each unit has a 7-stage double flow HP turbine exhausting to a two-stage MSR, the reheat steam entering three 8-stage double flow LP turbines with 45" last stage (L-0) blades.

Reasons For HP Turbine Retrofit

Industry experience with the ABB-CE design steam generators together with SONGS NDE results indicated that intergranular stress corrosion cracking of SG tubing is the most significant life-limiting degradation mechanism. This phenomenon is known to be thermally activated and can be mitigated significantly by lowering the operating temperature.

The objective of reducing SG operating temperature was to extend service life of the SG without incurring the considerable expense of equipment replacement and to avoid lost plant output associated with high levels of SG tube plugging.

In order to determine the desired new operating temperatures a study was performed. The competing factors which dominated this study were the effects of decreasing steam pressure associated with reactor coolant system (RCS) temperature reduction and sharp decrease in plant output, since the amount of steam which the HP turbine can pass is directly proportional to the inlet steam pressure. A way needed to be found to direct the same amount of steam to the turbine with lower main steam pressures. The increase in flow area could be achieved by fitting new diaphragms in the first three HP stages with larger throat areas. In addition, the steam generators were chemically cleaned to remove heat transfer fouling deposits from the secondary side of the tubing. The result was a determination that RCS could be lowered by a total of 13°F and still pass the original full power steam flow to the turbines.

HP Turbine Modifications

The steam flow from the SG has two parallel paths: nominally 95% to the HP turbine, and the remaining 5% to the MSR (Fig. 1). It was therefore important to know both the absolute level of steam flow from the SG and the proportion of steam to each component, prior to making any changes to the HP turbine - too big an increase in capacity would lead to inefficient HP valve throttling in order to maintain steam generator outlet pressure, whilst too small an increase would not allow the full potential benefit of the reduction in RCS temperature.

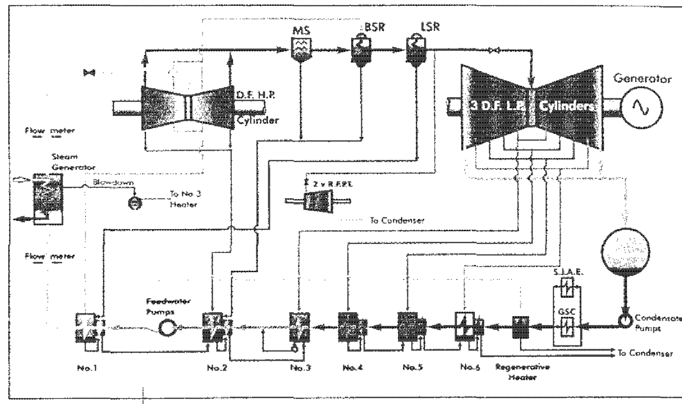

Fig.1 San Onofre Secondary Plant Cycle (Diagrammatic)

Many test measurements, mainly pressures and temperatures, were taken on Unit 3 secondary plant. Together with the use of chemical tracers to estimate some cycle flows, these measurements allowed the actual operating cycle to be modelled by ALSTOM Power, and hence the consequences of both cycle and component changes to be predicted with reasonable accuracy.

The increase in HP turbine capacity was achieved by firstly modifying the HP turbine throttle valves to reduce the full-flow pressure drop when wide open, and then increasing the HP turbine flow area by fitting new diaphragms, with fixed blades having larger throat areas, in the first three stages.

ALSTOM Power manufactured the replacement fixed blades using its latest approach in which the fixed blades have integral root and tip platforms (Fig. 2). The fixed blade platforms are then welded directly into the diaphragm rings.

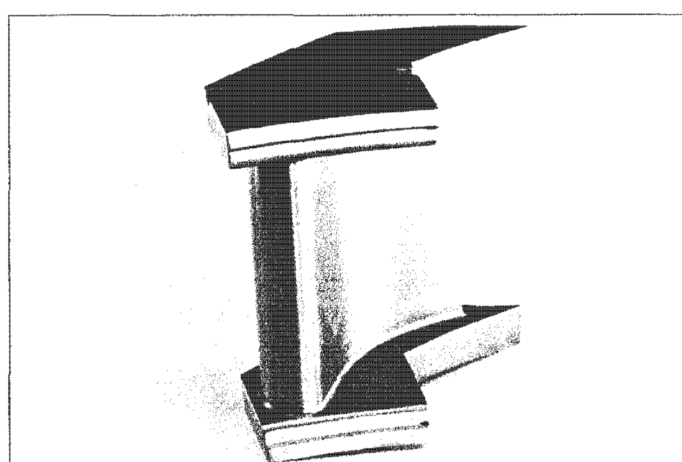

Fig.2 HP Turbine Fixed Blade

Reasons For LP Turbine Retrofit

The principal concern with the original LP turbines, in common with industry experience on units of similar construction, had been the discovery of SCC in the disc rim and balance hole regions of several rotor stages during the 1995 refuelling outages. These cracks were arrested by skimcutting, dressing out of larger defects, enlargement of steam balance holes and shot peening (Ref. 1). The discovery of SCC, together with the possibility of further SCC initiation at other vulnerable points on the rotors had lead to increased inspection requirements and the potential for extended or unplanned outages. A secondary reliability problem associated with the original turbine design included concerns over torsional resonance margins. (Ref. 2).

The temporary repairs performed during the C8 refuelling outages in 1995 were to permit operation of the turbines for one more cycle. Therefore, it became necessary to develop a strategy for managing the turbine cracking problem, to avoid costly and frequent inspections, and to ensure turbine integrity until the end of the licensed plant life. The purpose of this strategic plan was to provide the optimum approach for managing the LP turbine disc cracking. Based on the initial Unit 2 SCC findings, and subsequent Unit 3 findings, a multi-organizational team was formed to investigate various repair options that were capable of restoring the turbine rotors life in a timely and economical manner. The team make-up was chosen to address all aspects of a turbine refurbishment program.

Four options were considered (Options A, B, C, and D), ranging from the least cost to most cost respectively. The options included inspecting and repairing (A), refurbishing the rotors using two universal rotors as maintenance tools (B), purchasing three new rotors of an upgraded design (C), or purchasing 6 new rotors (D).

Of these options, Option D provided the least risk that cracking would not resume. Option C addressed the cracking problem, but did assume some risk since three of the rotors would be old, refurbished rotors. Option B was not realistic because it was maintenance intensive; and final rotors would not have been refurbished until the Cycle 12 outages. Finally Option A assumed a great deal of risk since none of the rotors would have been replaced, and all repair work planned had to occur during the outages. This option could not guarantee that cracking would not resume, and the risk was the economic impact the plant would have faced if cracking became worse than predicted.

The results of the present worth cost evaluation indicated that Option C, the purchase of three new rotors, was the strategic solution for addressing the LP Turbine cracking. However, factors such as the additional MWe gain and more competitive pricing, obtained during the bidding process, economically justified Option D, installation of 6 new and upgraded LP turbines.

LP Turbine Retrofit

In order to satisfy the twin objectives of eliminating the threat of SCC, and providing a substantial performance (MWe) improvement, the retrofit LP turbines had two important changes in turbine architecture compared with the original machine (Fig.3).

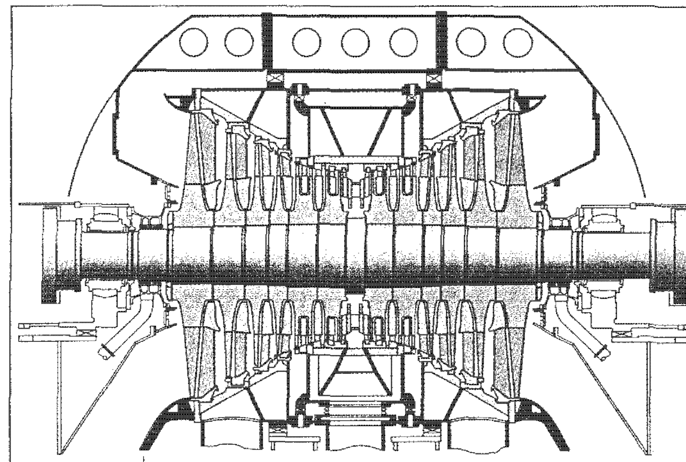

Fig.3 Original LP Turbine Design

SCC Avoidance

The San Onofre LP turbine retrofit (Fig 4) is based on the use of welded rotors constructed from two shaft ends and three intermediate "disks" assembled together by a highly automated welding process. Welded rotor technology has been applied by ALSTOM Power on large nuclear units since the 1970s.

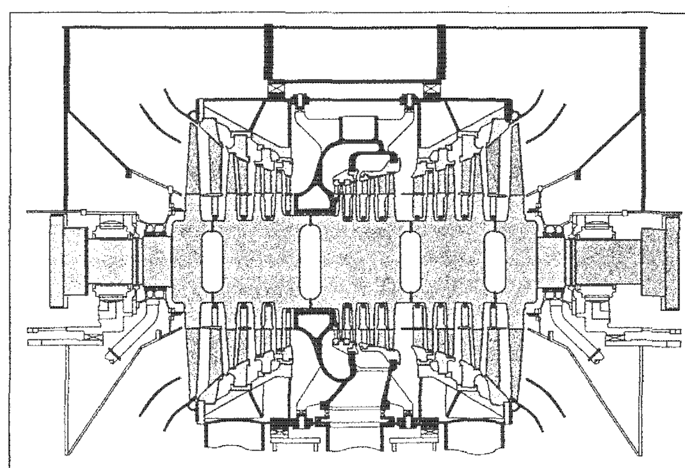

Fig.4 "Optiflow" LP Turbine Retrofit

The welded rotors do not have the high bore stresses and consequent high material strength associated with shrunk-on disc construction. The smaller forged pieces allow better control of material properties and are easier to inspect ultrasonically. The welded rotors never require a centreline bore for verification of bore properties.

The rotating blades on all stages except the L-0 and L-1 have forked-pinned root attachments in place of the older fir-tree (straddle) type. The pinned root fixing has much lower peak stresses for an equivalent blade load than the

IP7011277

fir-tree type. The elimination of the shrink-fit stress and the reduction in disc rim peak stresses allows the rotor yield strength to be specified 15-20% lower than an equivalent shrunk-on disc rotor.
Discussion on the results of extensive ALSTOM Power research into the causes and the avoidance of SCC is given in Ref 3.

Performance Improvements

The second major design change over the original double flow LP turbine design is the adoption of the unique ALSTOM Power "Optiflow" LP turbine configuration, developed to maximize performance.

The new LP blade path comprises a single flow (Optiflow) section with four stages of blading, followed by a conventional double flow section also with four stages (Fig 4). Steam enters the LP turbine inlets and divides three ways (rather than the original six) as it expands through the Optiflow section (Fig 5). The flow then divides into the double flow section and expands down to condenser pressure via longer, 47" L-0 blades and larger LP exhaust hoods.

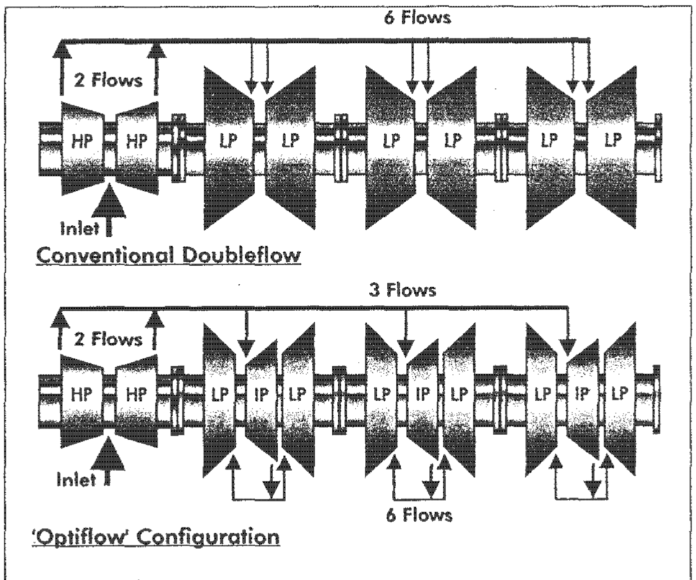

Fig.5 Comparison of Inlet Arrangement

The Optiflow principle is applied by ALSTOM Power to avoid the use of short and inefficient blades in the early stages of LP turbines. The increased blade aspect ratios (blade height/width ratio) - effectively doubled compared to conventional double flow arrangements - provide a distinct improvement in early LP stage efficiencies. This more than outweighs the sum total of flow reversal and leaving loss at the end of the single flow expansion and the leakage through the inlet gland seal.

All fixed and moving blades have modern high efficiency profiles and, with the exception of L-0 and L-1 stages, the moving blades have forked-pinned attachments and integral blade tip shrouding (Fig 6).

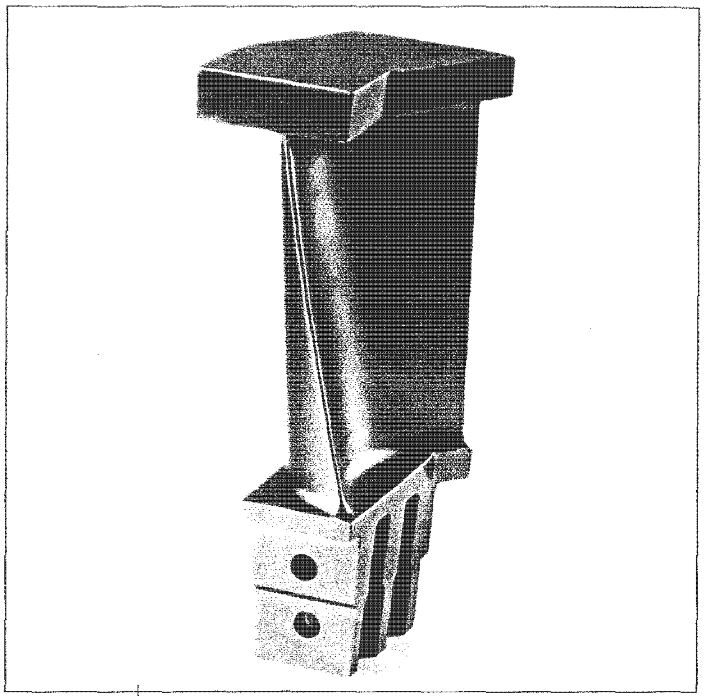

Fig.6 Typical Rotating Blade with Integral Shroud

Integral shrouding permits the application of both a smooth conical outer boundary to the steam path on the shroud underside and highly efficient labyrinth type seals on the shroud topside (Fig 7).

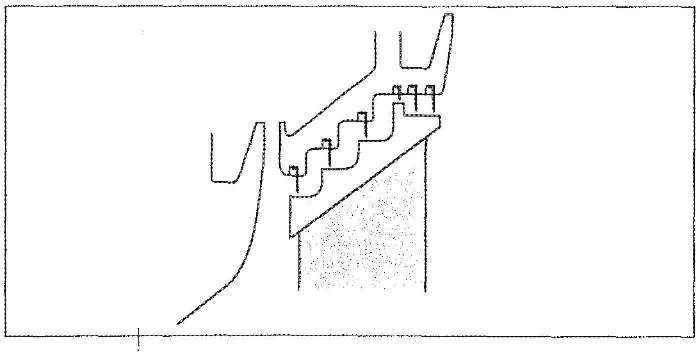

Fig.7 Typical Stepped Shroud for High Flare LP Blading

Spring-backed, slant-finned gland seals provide improved sealing at the diaphragm bores compared to the original design which had straight-finned, caulked-in seals.

The L-1 moving blade is a freestanding design with an axial entry root fastening.

The longer 47" L-0 blade improves performance by reducing the loss associated with residual kinetic energy in the exhaust steam at the design condenser pressure. A proven design, the L-0 blade has a highly cambered section, curved axial entry root fastening and integral snubbers (Fig 8).

IP7011278

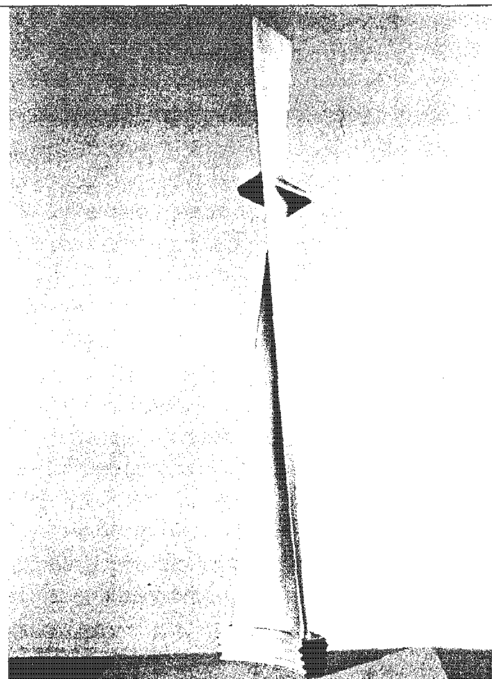

Fig.8 SONGS 47" Last Stage L-0 Blade

The original LP exhaust hoods presented a significant restriction to the steam exhausting from the last stage blade annulus because of their curved shape and short axial steam space (Fig.3). This restriction was removed by the design and installation of new generously sized hoods and exhaust flow guides (Fig 4), designed using state of the art computational fluid dynamics analysis tools.

The MWe improvement guaranteed by ALSTOM Power was contractually required to be attributable to the LP retrofit only, for nominated terminal conditions, including constant reactor thermal power. As well as accounting for the improvements in steam path design as outlined above, the guarantee also included a figure for degradation recovery of the existing LP turbines. The performance improvements (compared to the original LP turbine design) are detailed in Table 1.

Table 1 - Contributions to Performance Improvement

	Generator Output Increase %
Modern fixed and moving blade profiles, and Optiflow design.	1.1
Steam path flare (integral shrouds)	0.1
Improved moving blade tip and diaphragm gland sealing	0.3
Longer L-0 blade	0.15
Exhaust hood optimization	0.5
LP degradation recovery	0.15
Total	**2.3**

Performance Test Plan

SCE specified inclusion of a performance test provision in the contract to assess performance change of the turbines. Utilities facing similar retrofit should consider a test which can provide the following benefits:

♦ Meaningful contractual warranty,
♦ Accurate performance gain assessment,
♦ Early identification of the possible retrofit problems,
♦ Increase OEM focus on maximizing possible performance gain during design and manufacture,
♦ Very useful byproduct is overall plant conditions analysis which helps to identify any inherited performance problems, such as leaking valves, heat exchanger problems or inaccurate instrumentation

Technical Difficulties

It was clear that the test needed to be accurate enough to achieve the established objectives. All reasonable efforts were made to decrease uncertainties as high uncertainties could diminish or even eliminate completely all of the potential benefits. For example, there would be no reason to perform a contractual test with an uncertainty of say 10 MWe, when trying to measure a 10 MWe improvement.

There is no easy way to assess relatively small performance changes even under the best theoretical conditions. It is very common to obtain significantly different results when two measurements are taken on the same turbine generator set one or two days apart, even without parameters changing. It would become more complicated in real life when Pre and Post modification tests may be performed six months apart, as various uncertainties increase significantly and new variables need be taken into account. Some major uncertainty contributors are listed below:

♦ Instrument drift
♦ Instrument calibration between the tests
♦ Equipment aging and degradation
♦ Outage repairs (i.e. steam path, leaking valves, MSR, heaters)
♦ Operating parameters change which station has control of (live steam pressure, blowdown flow. gland steam flow, reactor power, power factor, heater bypass, etc.)
♦ Operating parameters change outside of the station control, such as condenser backpressure, heat exchanger efficiency.
♦ Impact of other major equipment modifications, such as HP turbine steam path modifications or SG pressure change.
♦ Steam cycle isolation.
♦ Unidentified leaks.

It would appear that the best method to assess efficiency improvement resulting from the LP turbine replacement would be to perform a full scale ASME PTC-6 Performance Test which provides the most accurate information about the components performance with a minimum uncertainty. However there are significant problems with such an approach. The major obstacle is the significant cost involved. Furthermore, it is a common practice for all major OEMs to guarantee relative MWe improvement, not absolute post retrofit MWe, because a significant part of the aged plant equipment is not impacted by the retrofit and is outside of the OEM's control. Therefore, two full scale PTC-6 tests, one before and one after the retrofit would be required to answer the main question of what MWe improvement was achieved. This would double the cost making a full scale test approach even more expensive.

In our case SCE and ALSTOM Power agreed that high accuracy could be achieved without the expense of full scale PTC-6 tests. Particularly it was agreed to perform back-to-back alternative tests per ASME PTC 6-1, relying on less measurements and analytically accounting for all changes and modifications made during the implementing outage and all other factors listed above.

Plant-vendor Agreements

All major agreements between SCE and ALSTOM Power were reached in advance during the contract negotiating phase. The Performance Test Plan was developed later and approved by both parties in order to formalize all details, most issues were treated per Test Code recommendations. Following are major components of the Test Plan:

- Test timing.
- Credits for non LP turbine outage modifications.
- Instrumentation details
- Plant isolation details
- Data collection details
- Prevailing conditions during each test run
- Data reduction
- Test acceptance criteria
- Data corrections
- Cycle loss calculation methodology

Two items from the above list are of particular interest. The first is test timing. In order to minimize uncertainties resulting from the instrumentation drift it was agreed that the Pre Test would be performed within 90 days prior to the Outage and Post Test would be performed no later than 90 days after the Unit returns to full power operation. The goal, however, was to perform a Post Test earlier, to further decrease instrumentation drift effects. Another point of interest is data correction. It was agreed that any deviations of the test conditions which could not be eliminated, such as condenser vacuum would be normalized using accepted correction curves. The main question, however, was how to handle additional plant modifications such as SG pressure reduction, condenser modifications and especially HP diaphragms modification, described above. All these changes were outside of the original scope of work and it was expected that they could have impact on the overall result of up to 20-25 MWe.

As HP diaphragm replacement was not part of the original LP turbine retrofit contract, its impact needed to be separated from the LP turbine retrofit impact. The problem was that in addition to calculated HP MWe impact value, the HP retrofit had significant uncertainty which depended on the diaphragms manufacturing tolerances and therefore could be fairly high. A solution was found using the fact that there is strong theoretical correlation between the diaphragm area and upstream pressure, therefore it became possible to calculate corrections to the test data by measuring HP 1st stage pressure before and after the outage. It should be noted, however, that these additional variables increased overall test uncertainty.

One more interesting issue was of how to assess the performance gain from the new generously sized exhaust hoods and aerodynamically designed diffusers (see Fig. 4), which were the part of the original contractual performance warranties. The hoods and diffusers were installed separately two years before the LP rotors replacement outage. The expected performance gain for this part, provided by ALSTOM Power was 0.5% (see Table 1), which corresponds to 5.5 MWe of overall electrical output. Such a small performance improvement could not be reliably measured. However, as SONGS noticed significant output increase using station instrumentation and other secondary indications, it was agreed to account for 5.5 MWe output improvement without further testing.

Test Uncertainties

The alternative test produces higher uncertainties than the full scale ASME PTC 6 test. Ref. 4 states that expected test results for steam turbines operating predominantly within the moisture region have an uncertainty of about 3/8% for the full scale test and 1/2% for the alternative test. Half a percent uncertainty would correspond to 6 MWe for the Pre test and 6 MWe for the Post test in the SONGS case, resulting in overall test result uncertainty as high as 12 MWe. This extremely high uncertainty would make the full scale test approach less suitable for contractual purposes.

It is important to note that test uncertainty is not the same as test tolerance. Test uncertainties are statistical values calculated in such a way that they bound real test results in 95% of the cases. If an arithmetic sum of the Pre and Post test uncertainties were used for back-to-back tests, the theoretical probability of the overall test result being outside of this range would be even smaller. This is because Pre and Post test results would need to be significantly biased in the opposite directions to make this happen. The probability of such an event is negligibly small as shown below using probabilistic range of 95 to 99.5%
$P = 2^*(0.025)^*(0.134) = 0.0067$ (0.67%).
Test tolerances on the another hand are negotiated commercial

values which are used for warrantee purpose only. There is no good answer as to what value should be used in each particular case. Some authors even stated that the tolerances should not be applied to modify test results [Ref 5, page 227]. We believe that these values are subject of contractual negotiation which should be closely tied to other contractual issues. For this reason this subject is left outside the scope of this paper.

It was realized that it was necessary to decrease test uncertainties to more reasonable values in order to have meaningful data. Overall test uncertainty depends upon the cycle uncertainty or how well operational conditions are assessed, in addition to overall instrumentation uncertainty which in turn depends upon individual uncertainties (i.e. measurement errors) of the specific parameters. Test uncertainty of each particular instrument or parameter has two components:

- Systematic or fixed bias error,
- Random or precision error

The benefit of the back-to-back test methodology is that all bias errors are cancelled out as long as a number of special provisions is taken. Therefore, only the random error and cycle uncertainties remain. This makes accurate testing much easier. However, additional steps needed to be taken to achieve further test uncertainty reduction. The following approaches and solutions were used:

- Eliminate systematic (bias) uncertainty, leaving random uncertainty only [Ref 6. page 21]. The same instruments were used for the Pre and Post test without additional calibration between the two tests. Instrument drift between the tests was verified, however no calibrations were performed.
- Identify major contributors and improve accuracy for their measured values, using more accurate instruments. It was agreed to use main steam flow measurements instead of feedwater flow to avoid significant uncertainty resulting from possible feedwater venturi fouling. Additionally, high accuracy instrumentation was used to measure generator electrical output and power factor, final feedwater temperature, condenser vacuum, and first stage HP turbine pressure.
- Increase number of critical instruments (some installed by ALSTOM Power and some by SCE), taking statistical credit by averaging data obtained from multiple instruments. Electrical output was measured by 2 independent power analyzers, final feedwater temperature was measured by 4 independent instruments, using 2 additional permanent station instruments as reference points, condenser vacuum was measured at 9 different locations using a total of 18 instruments (6 new condenser vacuum basket tips per Code [Ref. 4] were installed in addition to three existing station instruments), and 1st stage HP turbine pressure was measured by 4 independent instruments.
- Collecting more raw data by increasing frequency readings, the number of data collection periods and duration of these periods. Each test consisted of two successive two hour test periods. Data for all critical parameters were collected every 1 minute, resulting in 240 raw data points for each critical parameter.
- Controlling operating parameters and keeping them steady. It was necessary for the SONGS operators to keep primary and secondary cycles in a stable and steady condition, using following limits as a guideline:

o Generator electrical output	±3 MWe
o Steam generator pressure	±4 psi
o Reactor power	±0.25%
o RCS reference temperature	± 0.5°F

- Keeping Post test conditions as close to Pre test operating conditions as possible eliminating extra variables.

o Isolate Steam Generator blowdown. (Unfortunately, plant chemistry conditions would not allow us to shut off blowdown during the Post Test).
o Condenser makeup was isolated
o Reactor power was kept the same for both tests
o Secondary plant alignment including number of operating pumps, feedwater heater levels, emergency dump valves position was kept the same.
o Condenser backpressure maximum value was limited in order to minimize vacuum correction

- Decreasing overall test confidence level from 99.3% to a more reasonable value of 95%

The overall uncertainty of the test was calculated based upon the above considerations and it was concluded that the value of ± 0. 17% with a confidence level of 95% could be achieved for each test. This corresponds to the overall back-to-back test uncertainty of approximately ± 3.5 MWe with confidence level of 95% which was believed to be adequate for this particular test purpose.

Measured Improvements

The pre test on SONGS 2 was performed 65 days before the planned Outage. The intention was to have enough time to repeat the test if things did not work out as intended. Everything went as planned and a baseline was established.

The first Post retrofit estimation was performed five days after SONGS 2 reached full load. This estimation was performed for the primary purpose of obtaining a quick assessment of the performance changes. Corrected LP turbine MWe improvement was calculated to be 23.2 MWe. It was felt at that time that five days could be not enough time to stabilize all parameters and to identify all potential cycle leaks. In addition, test timing was not optimal due to an unusually high number of variables such as extremely high vacuum, high SG blowdown flow, abnormal auxiliary steam alignment, etc. All these factors resulted in the large correction factors, increasing overall test uncertainty. In order to decrease the uncertainties, the Post test was repeated three more times 12, 55, and 85 days after the outage completion. The results obtained during all four Post retrofit tests were normalized to design conditions using the correction curves and formulae. All four Post retrofit tests, performed under very different operating conditions, provided very close results. This gave us a high confidence level in the obtained results. The difference between the

Pre and Post tests electrical outputs provided documented performance improvements as shown below. See table 2.

Table 2 SONGS Unit #2, Pre- And Post- Cycle 10 Outage Retrofit Test Data

	PRE-TEST	POST-TESTS			
Test date	10/27/98	3/2/99	3/9199	4/22/99	5/23/99
Reactor Power (%)	100.00	99.90	100.09	100.11	100.06
Measured Elec. Power Corrected to 100% MWt	1161.033	1175.209	1173.192	1171.621	1168.344
SG Pressure (psia)	872.21	830.62	817.01	806.40	804.89
1st Stage Press-Corrected to 100% MWt (psia)	783.74	706.61	707.15	708.92	708.81
1st Stage HP Pressure Correction (MWe)	NA	21.365	21.213	20.723	20.754
Condenser Vacuum Correction (MWe)	3.834	-12.403	-10.887	-7.024	-3.142
SG Blowdown Correction (MWe)	0.000	3.100	3.100	2.320	2.320
Auxiliary Steam Correction (MWe)	0.000	1.200	1.200	0.000	-0.800
Miscellaneous Corrections (MSR outage repair, Leakages, Steam Traps, Power Factor) MWe	0.850	0.480	0.525	0.300	0.650
Normalized (corrected) MWe	1165.717	1188.950	1188.344	1187.941	1188.126
NET LP Turbine MWe Gain for each test	N/A	23.232	22.627	22.223	22.409
Average MWe Gain Due to LP Turbine Retrofit			**22.62 MWe**		

Conclusions

1. The methodology and technology discussed in this paper can be applied at nuclear power plants with a need to replace or modify their turbines. Significant performance gains can be achieved, with relatively straightforward verification, while simultaneously addressing long term equipment maintenance concerns.
2. The new ALSTOM Power HP turbine diaphragms reduced 1st stage pressure by 74 psi with a respective reduction in Steam Generator pressure from 872 psia with Valves Wide Open to 830 psia with some remaining throttling on the Governor Valves. This pressure reduction was greater than was anticipated allowing SG temperature and pressure to be dropped further by fully opening the turbine inlet valves. Thus, optimum Steam Generator life extension operating conditions were achieved without additional plant modifications with performance limiting consequences.
3. Installation of the new ALSTOM Power "Optiflow" LP Turbines have effectively improved SONGS 2 electrical output by 22.62 MWe versus the 21.5 MWe anticipated. Further, the generous exhaust hoods and modern diffusers, installed ahead of time, have accounted for an additional 5.5 MWe improvement. Therefore the overall LP retrofit improved SONGS 2 electrical output by 28.1 MWe.
4. As a side benefit, numerous existing problems with plant equipment and instrumentation were identified as a result of the performance testing. For example, a significant difference of 3.485 MWe was noticed between the test quality Power Meter installed for the tests and installed plant instrumentation. Resolution of these issues has helped to further improve plant electrical output and efficiency.

References

1. Russell J. Chetwynd, Riyad Qashu, Nabil El Akily, Ralph J. Ortolano, March 1997, "Arresting Stress Corrosion Cracks in Steam Turbine Rotors", Baltimore MD. EPRI Steam Turbine SCC conference.

2. Russell Chetwynd, Mehrdad Hojati, and David Palmer: "An Evaluation of the Limits to Safe Operation for Low Pressure Turbines with Low Margins from Torsional Resonance." (paper originally presented at IJPGC San Francisco, July 1999)

3. John McCoach, Russell Chetwynd, and Jorge Morales. Successful Implementation of HP & LP Turbine Retrofits at San Onofre Nuclear Generating Station. EPRI's Steam Turbine Generator Workshop & Vendor Exposition, St. Louis, August 17-20, 1999

4. ASME PTC 6-1-1996, ASME Performance Test Code 6 on Steam Turbines. ISBN 0-7918-2372-5.

5. K.C. Cotton. Evaluating and Improving Steam Turbine Performance. ISBN 0-9639955-0-2

6. ANSI/ASME PTC 19.1 1985, Measurement Uncertainty. Supplement to ASME Performance Test Codes

7. J.A. Booth and P. Schofield. Testing to Detect Changes in Performance of a Steam Turbine Cycle. EPRI Heat Rate Improvement Conference, May 10, 1988

0001\700 STB

ALSTOM

ALSTOM Power - Newbold Road, Rugby. CV21 2NH. England
Tel: +44 (0) 1788 57111 Fax: + 44 (0) 1788 531700

IP7011283